Historical seismicity analysis of the mainshock and aftershocks of 1857 Ft. Tejon earthquake, San Andreas fault, from Ft. Tejon

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Project Summary

We examined the historical records for the 1857 San Andreas main shock, using many new sources not reported in Agnew and Sieh [1978] or Meltzer and Wald [1999], relying on a wide range of historical documents and sources over a a three-year search window. These data reveal that the earthquake was probably larger than previously interpreted, with a significantly larger region of Mercalli index VII or greater. High-quality reports from near the fault indicate significantly higher amounts of ground shaking, with MMI values of XI or even locally XII. The sites are sparsely but widely distributed across the region, allowing us to estimate a felt are of ~360,000 km^2. Local site effects indicate an extremely strong local ground rupture and shaking occurred.

Introduction

Historical seismicity – the analysis of the descriptions of the effects of ground shaking from an earthquake based on historical reports, diary entries, chronicles, newspaper reports, inscriptions, and even folklore, provides critical information on pre-instrument era earthquakes. Data from historical seismicity may constrain the location of faults, the nature of ground shaking, areal distribution of deformation, and the nature of deformation in man-made structures, which can be used for a macroseismic analysis (Guidobini, 2002). Historical seismicity has been used in Europe to examine large events (Mayer-Rosa and Cadiot, 1979) and the method can extend the record of large events 500-2000 years in some places (Amiran et al., 1979) and extends the understanding of seismicity in remote areas (Ambraseys and Bilham, 2003). In the United States, historical analyses includes the 1811-1812 New Madrid earthquakes (Mueller et al., 2004), California earthquakes (Agnew and Sieh, 1978; Toppanzada, 1998, 2002; Meltzner and Wald, 1999) the Pacific northwest (Ludwin, 2002) and the Basin and Range (Evans et al., 2003).

The historical analysis of the great Ft. Tejon earthquake in 1857 (Agnew and Sieh, 1978) and its geomorphic analyses (Sieh, 1978; Grant and Sieh, 1993, 1994) clearly document the earthquake to have been along a 360 km length, incorporating the Cholame, and Mojave segments of the San Andreas fault [Figure 1]. The 1857 event was the last major rupture along the southern part of the San Andreas fault. The region was very sparsely populated in 1857, with ~ 370,000 people living in the entire state, but a U. S. military installation, Ft. Tejon, was located approximately at the midpoint of 1857 rupture. Up to 9 m of dextral slip occurred during the ~ Mw 8.0 earthquake (Sieh, 1978, Grant and Sieh, 1993, 1994), which occurred at about 8:20 am local time (Meltzner and Wald, 1999). Agnew and Sieh (1978) compiled 60 reports from the region and assigned Mercalli felt indicies to each report to show that the earthquake was felt over much of California and western Nevada. Maximum MMI values of VIII & IX were assigned by Agnew and Sieh (1978) in the area near Ft. Tejon, including a ranch two miles south. Sieh (1978) suggest that at least 5 foreshocks and aftershocks from the 1857 Ft. Tejon earthquake were examined by Meltzer and Wald (1998) and they suggest that the earthquake exhibited a "typical" logarithmic falloff of aftershock requency as a function of time. Sieh (1990) suggests that the rupture nucleated along the Cholame segment of the fault,, approximately 160 km NW of Ft. Tejon, and was perhaps triggered by a M 6.0 earthquake along the Parkfield segment. The rupture propagated unilaterally from the NW to the SE (Ellsworth, 1990) and terminated in the Wrightwood area. Agnew and Sieh (1978) was felt over much of California and western and southern Nevada.

The purpose of our project was to provide further documentation to the nature of the main shock of the 1857 Ft. Tejon event as well as near-source aftershocks documented by soliders living at the fort. Due to its location and timing, relatively little was know about this great earthquake, and we focused on determining if previous earthquake magnitude estimates are consistent with our felt region data.

Methods

Owing to the importance of the 1857 Ft. Tejon earthquake for understanding seismicity on the SAF, the nature of the historical records, and to the fact that Agnew and Sieh (1978) did not consult a number of archives and records, we re-examine the historical reports of the earthquakes and discovered several new sources of data.

We used unique records housed in The Church of Jesus Christ of Latter Day Saints (LDS) archives in Salt Lake City, the National Archives, Washington D. C., where reports from Army records are kept, the Huntington Library, California, and the California State Archives to examine details of the nature of ground shaking and rupture of southern California during 1857 event. We also examined numerous smaller historical societies, archives, and libraries, and evaluated the records of newspapers throughout California up to 3 years after the earthquake. The analysis includes translated Spanish and German language newspapers from the Los Angeles region. Our work has uncovered 179 reports in addition to those of Agnew and Sieh (1978), and our work has added great detail to the nature of ground shaking at many sites. We used a historigraphic approach to the records of the time, which employs historical methodology as taught within the historical field. The process consists of establishing a background understanding of leading experts' published reports and outlining materials previously consulted---a historiography. We examine all sources within the search realm, including journals and other similar materials that list applicable dates, although no mention of an earthquake is listed on the summary page of the collection. Due to a shortage of staff, often archives cannot fully list the contents of every collection and historians through research assist in updating various finding aids within facilities. At the conclusion of gathering data and contextual information, we assigned Mercalli index to each report, using a scale that is most suitable for the times (ref). Other relevant information including time, direction, length, aftershocks, and unusual phenomena associated with the earthquake are included in the tabulation of data.

We focused on two aspects of the reports made by observers at Ft. Tejon earthquake. We examined regional records of felt reports from California and Nevada, and we also examined the reports of Maj. Peter G.S. TenBroeck and Lt. William Thomas Magruder. These written reports are part of a series of letters from these two soldiers to their commanders in the U. S. Department of the Pacific between 19 January 1857 and 2 February 1858, and are part of the standard report of post details of the time. These reports are newly discovered records, and provide proximity to the rupture, the high quality of the observations, and their importance regarding regional seismic risk analysis in California. Full transcriptions of their letters are included as supplemental material, and these transcriptions reproduce verbatim the relevant contents of the letters. Agnew and Sieh (1978) documented approximately seven reports from the Tejon personnel, which included the fort, ranch, and Indian reservation. A handful of newspapers reprinted portions of the initial letters or aspects of personal conversations between military and civilians. The accounts reported the nature of damage to buildings, and the nature of ground motion [in sometimes florid terms].

Due to the variation in the nature of reports in 19th century western United States, we typically assign a range of Mercalli indicies to a given report. Mercalli index assignment is made more difficulty by the nature of buildings at the time. The modified Mercalli index [MMI] was developed in 1931 [Wood and Neuman, 1931], and applies to 20th century buildings that consist of framing and masonry construction, much different from the single story adobe and post construction. We assigned an MMI value to each felt report using the modern MMI scale, in some places inferring an MMI value for the older building style. We note that Agnew and Sieh [1978] used a 1951 version of the MMI scale.

Results

A. Regional Data

We evaluated 179 felt reports from a total of 68 sites; of these, 39 are the same as Agnew and Sieh (1978). The reports we document are in addition to the 76 reports at 39 sites in California and one site in Nevada of Agnew and Sieh [1978]. We plot these data on a simple base map [Figure 1], along with the summaries of the nature of the felt reports and the estimates of the Mercalli indicies we assigned to each site [Appendicies 1-3]. The regional results are relatively simple to summarize. Our data indicate two key points:

1. The documentable felt intensity over the 1857 earthquake were larger than that shown by Agnew and Sieh [1978]. In almost all cases, we were able to verify with two or more reports that the nature of shaking was likely larger than previously thought. For example, in the San Francisco area, damage to homes built in the Mission district were significantly damaged [and this was well reported, down to street addresses] and a seiche out of San Francisco Bay nearly overturned a ship in the Golden Gate. Similar increases in MMI values are documented in most of the sites Agnew and Sieh [1978] discussed; these are corroborated with new reports nearby.
2. Our data indicate that some of the increased MMI sites are at significant distances from the inferred epicentral region. We feel that the Los Angeles and San Francisco areas had significant ground shaking from the 1857 event, as did portions of the Great Valley.

B. Local observations

Captian Peter Stuyvesant TenBroeck was the Assistant Surgeon at Ft. Tejon in 1857. As evident by his career choice and from his letters, he was likely in a class of "scientists" who would make and record observations of a variety of natural phenomena. Few true geologists or even a consistent geologic education program existed at the time, and we suggest that TenBroeck's background would be similar to other amateur, reasonably well-educated mid-19th century natural scientists. Subsequent to his service at Ft. Tejon.

Lt. William Thomas Magruder of Maryland was Fort Tejon's Quartermaster, primarily responsible for the supplies, housing and other relevant duties related to the management of troops. Thus, both of these obsververs appear to have been well educated and observant for the times. Both men wrote a regular set of reports to their superiors in Washington, and the one of TenBrock's letters, summarizing the data show in Figure 2, is show in Appendix 4.

Ft. Tejon lies in a small valley astride the San Andreas fault, and the valley is bounded by granitic bedrock on the north and . In 1857, the post consisted of square to rectangular set of buildings, with a small assembly and parade grounds in the middle. Reconstructed buildings at the Ft. Tejon State Park fairly accurately reproduce the style and location of these buildings.

The tenBroeck letters used in this paper are from the National Archives, Washington, D. C., where the correspondence between the western forts and the Army headquarters are stored. The first tenBroeck letter was written shortly after the main shock, and provides a vivid report of the event. TenBroeck's report of the main shock begins:

"Our quarters here are much injured, some of them being Completely ruined, but the peculiar make of the roofs, have Saved the most of them, from utter destruction."
"My hospital is a wreak, and my sick have been in a hospital tent since the first Shock. I had just put my last received medicines Upon the shelves of the Surgery, and the Earthquaque has made a sad mixture of them ….[I] was unable to keep my feet, being thrown upon my face. And men were thrown from the top to the bottom of the Hospital stairs. "

"Just above the garrison oak trees, 8-10 feet in diameter were snapped off near the ground. One thing I remarked during the Shock, that the trees about me instead of bending in the direction of the vibration, seemed to bow themselves into a common centre."

Further descriptions indicate that while buildings at the fort were not completely destroyed, they were very damaged. The nature of the deformation of the oak tree seems accurate, and we infer that this was a Valley Oak [*Quercus lobata],* the largest and most common oak at this zone in California. Similar damage to the same species of tree was reported in the 1906 San Francisco earthquake [Jordan et al., 1907]. Further reports of the Ft. Tejon damage [Appendix 1] attest to an MMI value of XI or very locally, XII.
One of the notable aspects of the TenBroeck reports are the clearly documented number and nature of aftershocks in the region. He submitted a report some 6 months after the main shock with a table of the number of aftershocks, and separated the aftershocks into five categories, from "continous" to "slight". His data, summarized in Figure xx, show a drop off that is typical for large earthquakes [see also Meltzer and Wald, 1999]. Notable in his descriptions, however, are the nearly continous "rolling" nature of ground mtion the day or two after the earthquake, in which people were frightened and damage continued.

Conclusions

In this project, we examined hundreds of historical accounts of the 1857 great Ft. Tejon earthquake. We used newly discovered records, some not used by Agnew and Sieh [1978] or Meltzer and Wald [1999] to suggest that the earthquake was larger than previously estimated, with more significant felt reports at larger distances from the event. We also show that near source records indicate a stronger event, with damaging effect. The implications of this work are clear: earthquakes along the Carrizo Plain – Mojave sections of the San Andreas fault produce large local and far-field effects that are significan hazards to the state.

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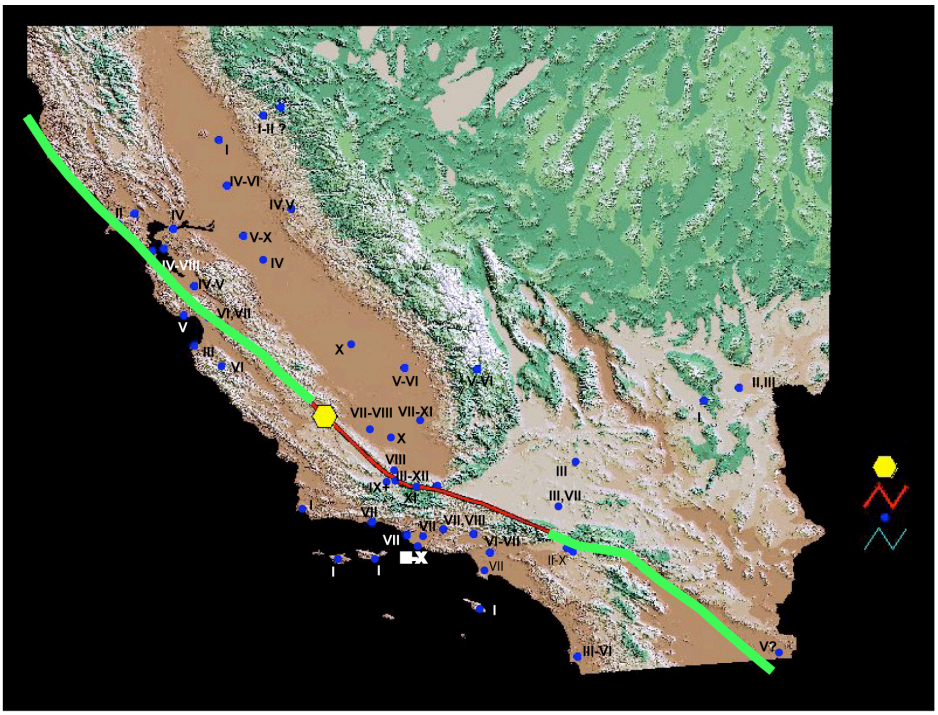


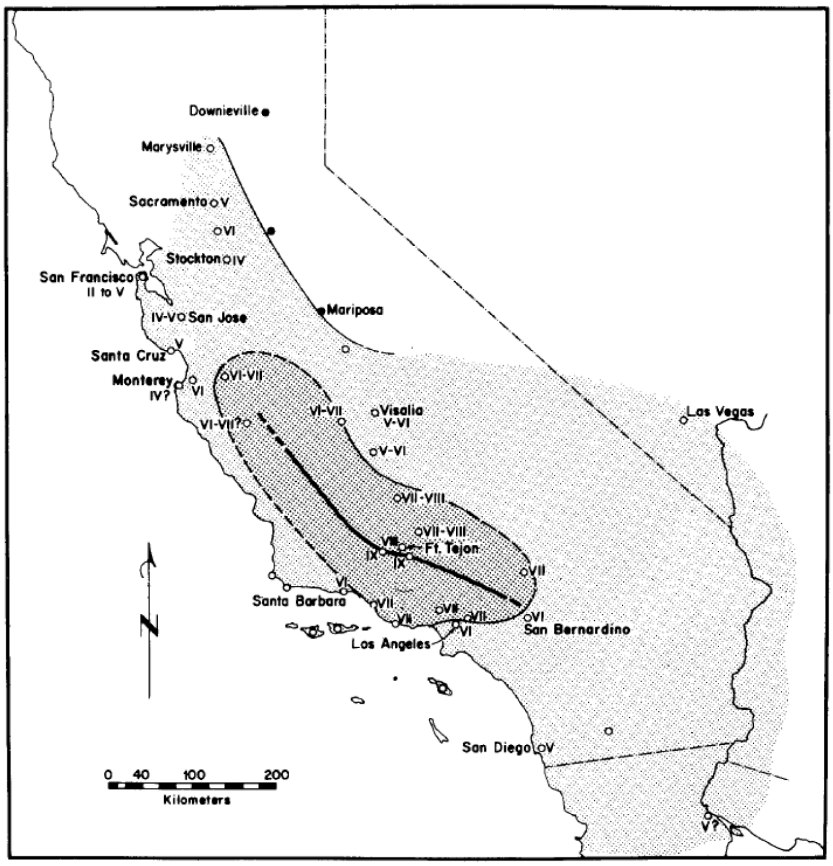
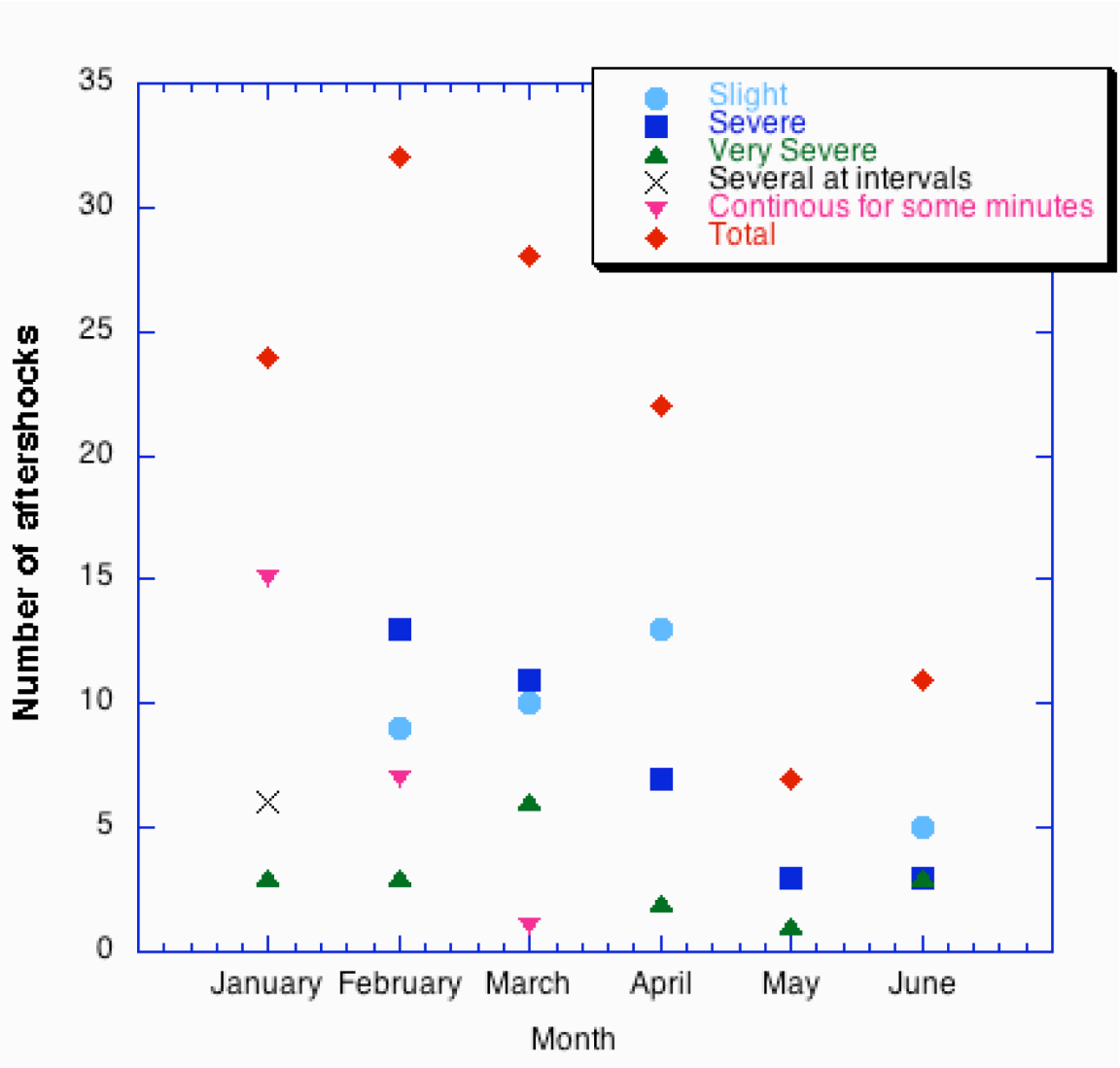


Figure 1. A. Shaded relief map of California and a part of Nevada, summarizing theresults of this work. The trace of the San Andreas fault is shown in green and red - the red portion is the portion inferred to have slipped in 1857 [Sieh, 1978; Grant and Sieh, 1993].

B. Results of the Agnew and Sieh [1978] analysis.


Slight
Severe
Very Severe
Several at intervals
Continous for some minutes
Total
Number of aftershocks
0
5
10
15
20
25
30
35
January
February
March
April
May
June
Month

Appendix 1. Summary of Felt Reports for California

BENICIA COUNTY
1. Aftershock: Jan 18

BENSON=S FERRY, SACRAMENTO COUNTY (at junction of Cosumnes and Mokelume Rivers)
1. Felt
2. Mokelume river (already swollen from rain) thrown over banks, stream bed almost bare
- Homes violently shaken
- Furniture overturned, glassware broken
- Tree limbs break
- Some trees sink 2-3 feet deep into earth
3. Several trees sink 2-3 feet deep

CAHUENGA COUNTY.
1. Violent shock
- Trees knocked around as if willows
- Earth turned up every way
- Man knocked down, could not get up for a time

CAJON PASS COUNTY
1. Men camping in canyon at night- 2 aftershocks at 9pm and 11 pm, not severe
2. Heard noise along mountains toward Cajon Pass
3. Mr Denton not sure if heard sound at night due to high winds in mountains

CAMPTONVILL COUNTY.
1. Aftershock: Sept 2nd, 7pm?, sensibly felt

CARPENTER=S RANCH COUNTY (near LA ?)
1. Dwelling house very much cracked

DOWNIEVILLE COUNTY
1. Aftershock; Sept 2nd, 7pm?, sensibly felt

FORREST CITY COUNTY.
1. Aftershock, Sept 2nd, chickens frightened from roots

FORT TEJON, TULARE COUNTY.
1. Felt in morning of 9th
- Serious Shock
- Lasted 3 to 5 mins
- Mexican woman killed
2. Remarkably severe
- Light shock observed about 6 am (foreshock)- barely perceptible
- About 8:30 am second shock
- Lasted 3 to 5 mins
- Sounded like rumbling of train cars
- Nearly all buildings in area seriously injured by fall of chimneys, plastering and walls
- Buildings being built and almost completed- totally destroyed
- Walls fall in on one bldg with kitchen
- Dr. TenBroeck violently thrown from his feet
* - 1 mile above fort, little girl almost die from limb falling from the shock.
* - Man in country, 20 miles from Fort says earth up heaved on road most likely from violent shock (traveling to Fort, northward)
* - Cowboy (vanqueror) further into mountains says roads almost impassable.
- Fall of house and trees, no injuries
- Shocks felt throughout day at short intervals
3. Shock severe
- Officer=s Quarters torn to pieces
- Hospital damaged
* - Buildings between Fort Tejon and Lake Elizabeth leveled to the ground
4. Serious earthquake, morning of 8th (seems to be a typo)
- Lasted 3 to 5 mins
- Shook down abode walls and chimneys
- One Mexican woman killed
5. Past Fortnight (from Feb 5th- fortnight=2 weeks) Aftershock. Chasms 10 feet wide x 40 miles long opened.
- Large streams form where none were before
- Great masses of rock and earth heaved high into air from lofty peaks
6. First shock at 6:30 am (Foreshock)
- Terrible shock at 8:33 am

- Tear officer=s quarters to pieces, severely damage hospital
- Gable ends of nearly all buildings lay on ground, including Quartermaster=s storehouse.
- Immense trees snapped off close to the ground
* - Bldgs between Fort Tejon and Lake Elizabeth leveled
- Continual shocks to Jan 11th
- Earth open in places up to 20 miles, line of damage run SE to NW
- Small stream beds enlarged to almost rivers
* - Immense number of fish through out of lakes
- Proceeded by rushing noise, for week after heard sound like distant thunder
- Large rent in earth 8 leagues (1 league= 3 statue/nautical miles; approx 24 miles) and 5 to 10 yards wide; passed Elizabeth Lake in SE direction; rent filled with earth or fissures.

7. 3 mins, vertical motion also
- rumble noise precede and accompany shock, hear noise (like thunder) for one week
- ground open 20 feet and close again, forming a ridge into the desert, NW to SE
- Aftershock; Jan 11

FORT TEJON MILL, TULARE COUNTY (about 12 miles west, or 20 miles from Fort)

1. Mules hauling timber thrown down
- Mill for time abandoned
- Branches of trees broken off
- Large oaks fell to ground

2. Heavy Shock
- Tore up large trees, twisted off branches
- Threw people on the ground

3. Mr. Botts in charge of Mill heard noise on Mtns south of Fort, looked at mountains and saw mass rock and earth issue from top peak, then felt shock. Noise proceed from that mountain before every succeeding shock.

IOWA HILL COUNTY

1. Aftershock: On election day, September ?, quite severe; rattle doors and windows; homes sway; people flee from homes, etc.

KERN LAKE COUNTY

1. Water in river forced back; rose over banks 4 feet

KERN RIVER COUNTY

1. US Troops in Kern River Valley - quake tip over coffee pots, kettles and soldiers
- Saw river run up stream
- River forced back and rose 4 feet over banks

LOS ANGELES COUNTY

1. Friday morning, 9th
- Severe shock
- Aftershocks on Sat, Sun, Mon
- People much alarmed
- No damage of any consequence
- Elsewhere others injured and one person killed
- Man between 80-90 yrs old walking on Plaza toward church, fell down and died (heart attack??)

2. 8:25 am, shock felt
- Start gradually and then increase to violent
- Every home rock side to side as if to topple over
- 3 distinct shocks
- Oscillating shocks
- Lasted 2 mins
- Travel N to S
- River (LA ?) thrown out of bed over banks
- Store good fell to floor
- Aftershocks: 8: 55 am, second shock, 3rd at abt 9:55am, several throughout day; 5pm shock almost as big as first. 11 pm another heavy shock- continue through night and next day. Jan 10 at 11pm sever shock, and on 11th continue through night.
- Move east to west
- Flee homes
- Oscillating as if swell on sea

3. Severe shocks

4. About 8:30 am, severe shock- vibrations last 2 mins
- North to South
- Aftershocks: 4 to 5 shocks during the day, less severe
- Several houses slightly cracked

- Doors slam to and fro
- Water turned out of bowls and pitchers
* - In [LA ?] river water rush between banks several times
- Move undulated (like wave) as field of wheat by the wind
- People rush out of beds, etc; frightened

5. Severe shock
- 8:25 am, shock felt
- Gentle at first (like someone shaking a table), to violent where every house and its contents rocked side to side
- 3 distinct shocks, perceivable to old timers of the area only
- Oscillating 2 full mins, North to South
- Aftershock: About 8:55 AM, another shock- less violent; about 9:55 am another shock; slight vibrations throughout day. 5pm shock almost as severe as first then slight till 11pm. Vibrations throughout the night; Saturday- several shocks, severe at 11 pm; Sunday- quiet till 11 pm with strong shock; Monday some reported shocks, but not all felt them.
- Rock tables, chairs and beds
- People rush outside; some woken up
- Horses, mules and cattle took to flight
- Birds (domestic and wild) flew wildly
* - The river [LA] out of its bed and receded
- Pools of standing water driven about, also in the zanja (ditch)
- Store good thrown/hurled down to floor
- Bottles broken
- Mill (upper end of town) pile of flour sacks overthrown
- Upper school house cracked in 1 place
- Aftershock at 11pm, people leave beds
- Mexican woman killed at Reed=s ranch interred (buried) in LA
- Aftershocks: Sunday and Monday morning

6. Aftershock: Jan 16th, 5pm, severe earthquake, move S to N, almost as strong as 9th
7. 2 mins, N to S and E to W, 3 distinct shocks
- Aftershocks: Jan 10, Jan 11, Jan 15

MARYSVILLE COUNTY

1. Aftershock: Sept 2nd, 7pm?, sensibly felt

MICHIGAN BLUFFS, PLACER COUNTY

1. Aftershock: Sept 2nd, severe; last ten seconds; bldgs sway to and fro six inches; people rush outside, dash glass jars from shelves and crockery from tables; clock came off wall.

THE MOHAVE COUNTY (may be near Mohave River- see below)

1. Shock quite severe

MOHAVE RIVER COUNTY

1. Upper Crossing (about 50 miles N/NE of San Bernardino); between 8 and 9 am heard noise, then violent motion followed
- Last 30 to 40 seconds
- Hard to keep on feet
- Move vertical and oscillatory
- Heard noise after in a N/NW direction like thunder, then grinding of rocks and crushing of mountains.
- Break and then heard sound again

2. Man at hot spring area when event happened; said shock in area so severe it would have leveled every building in San Bernardino
3. Vertical motion too
- Harsh grating noise before, noise after too

MOKELUMNE HILL COUNTY

1. Severely felt in region
- Shake hill around

2. Info from Pacific Express Co. employee- Jan 8 felt in evening (Foreshock?)
- Woke residents- rapid succession of slight shocks
- Windows and doors rattle
- Shock accompanied by flash of light from east to west

3. Report shake, but reporter believe event exaggerated

MONTE COUNTY

1. Men dashed to ground
- Horses over thrown
- Several houses greatly cracked, no persons injured though

MONTEREY COUNTY

1. Smart shock felt about 7am (Foreshock?)
   - Go NW to SE
   - Move like heavy, rolling wave
   - Horizontal Movement
   - Some felt it, others not
2. N and West to South and East

NEVADA COUNTY

1. Aftershock: Sept 2nd, 7pm, sensibly felt
2. Aftershock: crack court house from top to bottom; shook out lights in jail and scared prisoners; people ran out of court house.

OAKLAND COUNTY

1. Aftershock: Feb 5, sever shock felt about 7:30pm, no damage, people frightened

PETALUMA COUNTY

1. Aftershock: Nov 26, earthquake

REED=S RANCHO COUNTY (Six miles from Fort Tejon)

1. Woman killed by falling adobe
   - Several bldgs in area injured
2. House fell and killed woman, wall struck her head
3. Woman killed by falling beam
4. One home leveled to earth; Mexican woman (an inmate) killed

SACRAMENTO COUNTY

1. Shock of an earthquake, movement undulating
   - Direction from North to South
   - Alarm in most of city, little damage
   - One bldg sunk 1" and plaster shaken from walls
2. Felt
3. Severe Shock, 8:05 am
   - Brick bldg rock like ship to and fro by ground swell
   - Pendants on candelabra rattle
   - Pictures on walls swung like on a ship
   - Last 2 to 3 mins
   - 3 distinct, heavy rolls, yet continuous
   - Some people sea sick
   - Boats at Levee moved like roll of sea
4. Felt between 7am and 8 am
5. Felt a few mins before 8am
6. Felt at 7:45 am (Foreshock?)
7. Aftershock: Sept 2, 7 pm?, shock felt
8. Foreshocks: at 2:15 am
   - 8:15 am, last a few seconds
   - Chandelier vibrate 1" from center
   - Rattle crockery, etc
   - Move West to East, live waves
   - Move SE to NW, more horizontal
   - Chandelier move a few inches from center
9. Severe shock, at 8:19 2 mins, last just under 4 mins
   - Sensibly felt
   - Oscillatory SW to NE
   - Strongest tremble abt the middle of the Ashake≅
   - Compared to Feb 1856 event for San Francisco area
10. SE to NW, E to W, NW to SE, 3 distinct shocks

SAN BERNARDINO COUNTY

1. Shock severe
   - water from well white as milk (tribidity?)
2. 8:08 am, heave shock
   - Last 3 mins almost
   - Goods thrown from store shelves
   - Shock ranged from East, lasted 2 mins then changed to South
* - Heard noise afterwards along the mountains of Cajon Pass
   - Jan 10th a plummet (heavy object) suspended vibrated all day and hung sometimes up to 4 inches from center.
   - About 8am, severe shock
   - Lasted 2 mins, move North to South, undulating (waves)

- Rubble noise, feel giddiness
- People ran from homes
- Vibrations day and night from 9th to 18th
- Fissure in western part of city

* - Plains (near San Bernardino), felt shock violently and heard great noise.

3. 8:25 am, violent earthquake
   - Majority of home injured
   - Water in creek and ponds thrown over banks several feet high.
   - NW to SE
   - First shock, last 2 mins; 10 mins late second shock for 1 min, not sever (Aftershock)
4. 8:08 am, heavy shock, about 3 mins long
   - Shovels in store fell, tinware hanging swung every way
   - Earth moved like if on a ship
   - People run to street
   - Felt as if lasted 5 mins
   - Well water white as milk
   - Shade trees shock for ? mins afterwards
   - Two stores (Harris and ?; Chas Glaser) and school cracked
   - Came from East then South, lasted 2 mins; everyone feel drunk from effects
5. N to S, rumble noise with shock
   - 3 Shocks (8:24, 8:34, and 8:36) 8:38 shock with noise
   - NE to SW
   - Aftershock: Jan 10 and 17

SAN BUENAVENTURA COUNTY (present-day Ventura)

1. Severely felt
   - Caused roof of mission church to fall in
   - Stone built belfry damaged

* - 30 miles SW of San Buenaventura in a canyon (US Coast Survey team of WM Johnson), Shock at 8:24 am;
   - Vibrations heavy and violent, last 2 mins
   - Aftershocks: at 8:38 am, 8:36 am for 10 secs, 8:38 am with loud sound, 8:48 am- slight, 9:2? am- slight; 8:27 pm, 8:50 pm, 10:36pm- most severe
   - Vibrate NE to SW
2. Church nearly destroyed
3. Up to 9 distinct shocks; Aftershock: Jan 15

SAN DIEGO COUNTY

1. Felt at 8:45 am
   - Most severe ever remembered in the area
   - Caused great terror; people jump from beds and prayed
   - Boxes and bales thrown down in warerooms (a.k.a. storehouses)
2. Felt at about 8:30am, most severe
   - People rush from homes
   - Lasted several mins
3. Several homes thrown to ground
4. Severe shocks

SAN FERNANDO COUNTY

* 1. On range hills, 15 miles north near San Fernando, new large stream formed out of mountain and down canyon

* - On high mountain near San Fernando, fissure of extremely hot gas, local natives said further down mtn can see light.

2. New large stream where none before
   - Violent shock
   - Overturn two houses
3. Shock very violent
   - Knock down 2 houses, not effect mission bldgs.

SAN FRANCISCO COUNTY

1. Some bldgs shaken down
2. Shock felt in morning, about 8 am

- Begin near Clay Street, move to Ricon Point
- No boats move north of Clay St, boats South of line shake quite severe
- Clocks stop
- Tin pans and crockery upset
- Frame bldgs trembled, brick houses considered dangerous
- People frightened, ran out of rooms without fully being dressed
- No known bldgs cracked or injured

3. Violent shock
   - Known down 2 houses, not hurt mission bldgs (?)
   - At Mission (SF?)- shock severe, homes damaged, church cracked [Not clear if LA or SF]
4. Aftershock: Feb 5, smart shock- brick bldg rock, on side walk people lifted up and fall few inches, in area with land fill (man-made ground) felt more, shake down some bricks, iron shutters tremble and clatter, boxes of goods rattle, etc.
5. Severe shock, felt a few mins after 8am
   - terror and alarmed
   - more severe in lower part of city
   - Home of Peter J. Evans on corner of Market and California Streets, frame home shaken from foundation and moved several feet south. Home elevated 4 or 5 feet from planking, floor broke in several places
   - Clocks stopped
   - Gas burners shaken
   - Crockery and tin rattle in stoves
   - Hotel on Davis Street severe, cause boarders to rush to street
6. Slight shock about 8 am
   - Small wooden bldg at California and Market thrown down
7. Felt at 8:15 am
8. Aftershocks: Shock last evening (Jan 12th) at about 11 pm
9. Aftershocks: Feb 5th, 7pm, 2 shocks, sudden jar motion, large noise, 10 secs between shocks, terror in city, people ran to streets, esp from Montgomery Block and City Hall, cause alarm
10. Aftershocks: Feb 25 or 26, 1 am, slight
11. Aftershocks: Sept 2nd, slight shock, at 7pm?
12. Aftershocks: Dec 24th, 10 am, 3 vibrations, waves come from N. Felt at Mercantile Library Association, Sacramento Street, etc. Newspaper=s Publishers office tremble a few seconds.
13. Several shocks felt last evening and this morning (9th)- Foreshocks
    - Greatest just before 8 am
    - Felt slightly, not at all and greatly by different people
    - Severest in lower part of city
    - Move east to west
    - Shock at 11:20 pm (Jan 8th), Foreshocks; more at 1:33 am, 4:15 am, 6:?? am, 7 am and 8:14 am
    - Oscillatory from NE to SW
    - 8:14 am shock strongest
    - Lower part of city: furniture moved, crockery crash on shelves, glass jingle in cupboards
    - Heavy shock at 8:15 am
14. NE to SW, and E to W
    - Aftershocks: Jan 11, 20, 21; Feb 5; Oct 19, 20; Dec 24

SAN GABRIEL RIVER COUNTY (Near LA ?)

1. At Mr. Temples Ranch, earth rent asunder for considerable distance- ditch 3 feet wide
   - Disturbance for miles along the river
   - River turned out of bed many rods (1 rod=16 2 feet or 5 2 yards) in length

SAN JOSE COUNTY

1. Friday morning, 8:05 am
   - Severe shock felt in city
   - movement undulating and slow
   - Move SW to NE
   - Sickening sensation (sea sick), fainting, dizziness
   - Vibration slow and gradual
   - Last about 1 min
   - Artesian wells stop then gushed out more power than usual
   - Previously blocked wells now flowing
   - Shocks at 5 and 6 am (Foreshocks), distinct, short, and quick
2. Cut off or reduce volume of streams in several artesian wells
   - Some water stop entirely, others temporarily increased then return to normal (at the distillery)
   - Public fountain on Market- permanently reduced

3. Severe shock at 1 am (Foreshock)
   - Longer shock at 8:30 am
   - Move E to W, 1 min long
   - Only IMPORTANT damage (other damage occur) was cutting or reduce of streams to artesian wells, some gone- others increase and then back to normal
4. Sensibly felt
   - Affect artesian wells, One rose 12 inches and then fell 12 inches below normal flow. Rose and fell several times and then resumed normal course
   - One ceased entirely
   - Main well in city stopped and now barely runs
5. Move E to W, SW to NE

SAN JUAN COUNTY

1. Aftershock: Sept 2nd, 7pm, sensibly felt

SANTA AMELIA AREA COUNTY

1. Beds of small stream enlarged to almost rivers
   - Immense number of fish thrown out of the lakes and on to dry ground.

SANTA BARBARA

1. AOne hour past ??≅, most terrible shocks of last 46 years
   - Last 20 mins
   - Several homes injured
   - Residents flee homes
   - barely keep on feet
2. Up to six shocks
   - Nerves on edge
   - 1st shock at 6 am (Foreshock)
   - 2nd Shock at 9 am, for 1 2 mins, most severe ever felt
   - Most homes damaged
   - People and animals thrown down
   - Earth open in many places
   - Water gush up in some places 7 ft
   - Water in all wells rose from 10 to 20 feet
   - People frightened
   - Aftershocks: 3rd shock at 10am, slight; 3 more in evening (2 slight, 1 heavy)
3. Shock at 8:10 am, brief- unnoticed by many (Foreshock)
   - Heavy shock at 8:22 am, lasted 40 to 60 sec
   - People flee from homes
   - Earth vibrate side to side; rolling motion on sea
   - Roofs creak like beans of ship in a strong gale (wind)
   - Travel NE to SW
   - Fell adobe house walls
   - no noise or aftershocks
* - At beach, water and mud spout out of ground several feet high
* - Several new springs caused in mountains
   - Feel as if centrifugal motion of the earth stopped
4. Six shocks, 6 am (Foreshock) and 9 am, 2nd most severe
   - Most homes damaged
   - people and animals thrown down
   - Seven feet water in wells rose 10 to 20 feet more
   - People frightened, some have dizzy spells
   - Aftershocks: 3rd shock at 10am, 3 at night (2 slight/ 1 heavy)
5. Shocks severe
6. Aftershocks: Jan 16 at 4pm, heavy shock, yet brief, no damage, but felt in most of city- people flee homes; Jan 18- slight shock in morning; Jan 20- moderate shock on the night of 20th.
7. NE to SW
   - Mud and water spout up at beach
   - Aftershocks: Jan 15, 18, 20, 28

SANTA CLARA VALLEY/RIVER COUNTY (Near San Buenaventura)

1. Earthquake felt sensibly
2. Cracks running parallel to each other about 10 to 15 yards long in a NE to SW direction.
   - Blocks of earth sink down, 1 mile from mouth of river
3. Large cracks running parallel NE to SW, 10 to 15 yards
   - Square blocks of earth sink

SANTA CRUZ COUNTY

1. Aftershock felt on Tue; not as severe as 9th
   -aftershock rattle crockery

SEBASTIAN INDIAN RESERVATION, TULARE COUNTY (Approx 17 miles NE of Fort Tejon)

1. Some buildings injured

SIERRA COUNTY

1. Aftershock: August

STOCKTON COUNTY

1. Felt in city
2. Last 1-2 mins
   - Suspended lamps swing distance of 1 foot
   - 8 am or 8:20, first shock
3. Aftershock: Nov 26
4. 1 min duration

TULE RIVER COUNTY (100 miles from Fort Tejon, north)

1. Shock felt
2. Felt earthquake
3. About 8:30 am, felt, but no serious damage

TULES/TULAR LAKES AREA COUNTY (Near Stockton, San Joaquin Co?)

1. On bank of small lake man waiting for ducks, heard rustling noise in water like animal wading in shoal, noise lasted few moments.
   - Large swell roll and dash violently against shores
   - Run out onto plains several hundred yards
   - Man covered by swell 2-3 feet high
   - Seem to roll northward, like earth ceased (to move)
   -Waters settled down soon, became placid
   - Happen in morning, near time of earthquake in San Joaquin

* 2. Near Tular Lake (3 miles away), shock felt severely
   - 3 miles away could hear dashing of waves at Lake

3. Tular Lake- water lifted up
   - Large quantities of fish thrown onto banks

VISALIA, TULARE COUNTY

1. Slight rumble of earth, lasted 2 mins
   - The earth heave and roll (like sea waves)
   - Hard to remain on feet
   - Continue several mins, then deep rumble sound heard (like distant thunder or grating of large rocks)
   - Roll of ground under people seen as distinct as waves of ocean, made people feel seasick.
   - Waves like ocean after a storm
   - Tree tops vibrate back and forth several feet
   - Water in streams move bank to bank and out several feet
   - Vibrations NE to SW
2. Slight shock about sunrise (Foreshock)
   - Sever shock at 8:15 am, last number of mins (10-20)
   - Slight rumble for first 2 mins, earth roll like waves
   - Hard to stand
   - Another rumble heard like thunder or grating rocks
   - See earth roll like waves, feeling same

- 50 miles SE and N give similar reports
- Slight shock in evening at 8:45pm and 10:25 pm, last one severe (Aftershocks)

3. NE to SW
   - Noise after shock, like thunder
   - 10 to 20 mins

WHITE RIVER COUNTY (50 miles SE of Visalia and 50 miles N of Stockton)

1. Similar account as Visalia=s (as noted in first report - #1)

KEY: * indicated nearby location. Foreshocks and Aftershocks underlined for convenience

Appendix 2. Summary table of the Mercalli felt indicies assigned to each report, along with an estimate of the time, duration, and nature of the felt report.

Location	Intensity (MMI)	Time of 1st Shock	Length of 1st Shock	Direction Felt	Heard noise prior	Foreshock	# of aftershocks (Jan 9th)
Nevada							
Las Vegas	II,III	9 A.M	30 seconds	---	---	---	---
Potsi Lead Mines	I	in morning	---	---	---	---	---
California							
Benicia	---	---	---	---	---	---	Jan 18- 1
Benson's Ferry	V, VI, VII, X	---	---	---	---	---	---
Cahuenga	VII	---	---	---	---	---	---
Cajon Pass	---	---	---	---	yes	---	Jan 9- 2
Camptonvill	---	---	---	---	---	---	Sept 2- 1
Carpenter's Ranch	VII	---	---	---	---	---	---
Carricito	Felt	---	---	---	---	---	---
Downieville	---	---	---	---	---	---	Sept 2- 1
Forrest City	---	---	---	---	---	---	Sept 2- 1
Fort Tejon	III, VII, VIII, X, XI, XII	8:30 AM	3 to 5 mins	---	yes	6am	continuous for 6 months
- 1 mi N	VIII	---	---	---	---	---	---
- betn Fort and Lake Elizabeth	XII	---	---	---	---	---	---
Fort Miller	Felt						
Fort Tejon Mill	VII, VIII	---	---	---	yes	---	---
Iowa Hill	---	---	---	---	---	---	Sept
Kern Lake	X	---	---	---	---	---	---
Kern River	VII, X, XII	---	---	---	---	---	---
Lake Hughes/Mill Potrero	IX+	---	---	---	---	---	---
Los Angeles	III, V, VI, X	8:25 am; 8:30 am	2 mins	N to S; E to W	---	---	Jan 9- 4; Jan 10-1, Jan 11, 15, 16- #?
Millerton	II	---	---	---	---	---	---
Marysville	Felt	---	---	---	---	---	Sept 2-1
Michigan Bluffs	---	---	---	---	---	---	Sept 2
The Mohave	III+	---	---	---	---	---	---
Mohave River	III, VII	bwtn 8-9 am	30-40 sec	---	yes	---	---
Mokelumne Hill	IV, V	---	---	---	---	maybe	---
Monte	VII, VIII	---	---	---	---	---	---
Monterey	III+	7:00 AM	---	N to W; S to E; NW to SE	---	---	---
Mouth of Colorado River	V?	---	---	---	---	---	---
Nevada	---	---	---	---	---	---	Sept 2-1
Oakland	---	---	---	---	---	---	Feb 5- 1
Petaluma	---	---	---	---	---	---	Nov 26
Point Arguello	Felt	---	---	---	---	---	---
Point Conception	Felt	---	---	---	---	---	---
Reed's Rancho	X-XI	---	---	---	---	---	---

Sacramento	II, V, VI	7:45, 8:05, 8:15, 8:19	2-3 mins, few sec, under 4 min	W to E, N to S, SE to NW, SW to NE	---	2:15 AM	Sept 2- 1
Salinas River	VI	---	---	---	---	---	---
San Benito Ranch	VI-VII?	---	---	---	---	---	---
San Benito and River	VI-VII	---	---	---	---	---	---
San Bernardino	II, III, V, VI, VII, X	8:08 am, 8:25 am	almost 3 mins	E to W, then N to S; NE to SW	yes	---	Jan 9- Jan 18, # unknown
San Buenaventura	VII+	---	---	---	---	---	Jan 9- 9, Jan 15- 1
- 30 miles SE (canyon)	IV-V	8:24 AM	2 mins	NE to SW	---	---	Jan 9- 7
San Diego	III, VI, VIII	8:30 am, 8:45 am	several mins	---	---	---	---
San Fernando	VII	---	---	---	---	---	---
San Francisco	IV-VIII	8, 8:14, 8:15 am	---	E to W, NE to SW	---	11:20pm (jan 8)	Jan 11- 1, Jan 20-1, Feb 5-2
SF Cont						1:33, 4:15, 6:?, 7 am	Oct 19 & 20, Dec 24
San Gabriel River	VII	---	---	---	---	---	---
San Jose	IV-V	8:05, 8:30 am	1 min	SW to NE, E to W	---	5 am, 6 am	---
San Juan	---	---	---	---	---	---	Sept 2- 1
San Pedro	VIII	---	---	---	---	---	---
Santa Amelia Area	---	---	---	---	---	---	---
Santa Barbara	VI	9am, 8:10 am	1 1/2 mins, 20 mins (3 shocks?)	NE to SW	---	6am	Jan 9- 4, Jan 15, 16, 18, 20 & 22
Santa Catalina Island	Felt	---	---	---	---	---	---
Santa Clara Valley/River	---	---	---	---	---	---	---
Santa Cruz	V	---	---	---	---	---	Jan 12-1
Santa Cruz Island	Felt	---	---	---	---	---	---
Santa Rosa Island	Felt	---	---	---	---	---	---
Sebastian Indian Reservation	VII-VIII	---	---	---	---	---	---
Sierra County	I-II ?	---	---	---	---	---	Aug
Simi	---	---	---	---	---	---	---
Stockton	IV	8:00, 8:20 am	1, 1-2 mins	---	---	---	Nov 26
Sycamore Canyon	VII	---	---	---	---	---	---
Tule River	---	in morning	---	---	---	---	---
Tules/Tular Lakes Area	X	in morning	---	---	---	---	---
Visalia	V-VI	8:15 AM	2 mins, 10 to 20 mins	NE to SW	yes	sunrise	Jan 9-2
White River	V-VI	---	---	---	---	---	---

Appendix 3. Comparison of the felt reports of Holden [1989], Townley and Allen [1939], Wood [1955] and Agnew and Sieh [1978] with our work.

Location	Intensity				
	Holden (1898)*	Townley & Allen (1939)*	Wood (1955)**	Agnew & Sieh (1978)**	Evans & Martindale (2002+)**
Nevada					
Las Vegas	---	---	---	Felt	II, III
Potsi Lead Mines	---	---	---	---	I
California					
Benicia	---	---	---	---	
Benson's Ferry (Stockton/Sacramento RD)	--	--	Identify	VI	
Buena Vista Lake	--	--	Identify	--	
Cahuenga	---	---	---	---	VII
Cajon Pass	---	---	---	---	(Felt)
Camptonville	---	---	---	---	(Felt)
Carpenter's Ranch	---	---	---	---	VII
Carricito (SD, Co?)	--	--	--	Felt	Felt
Cholame Valley	--	--	Identify	--	
Downieville	--	--	--	Not felt	
Elizabeth Lake	--	--	Identify	--	
Forrest City	---	---	---	---	
Fort Miller	--	--	--	Felt	Felt
Fort Tejon	IX	IX	Identify	VIII	III,VII,VIII,X,XI,XII
1 Mile north of Fort	---	---	---	---	VIII
Between Fort and Lake	---	---	---	---	XII
Fort Tejon- 2 miles south	Intensity unassigned	IX, X-at epicenter	Identify	IX	
Fort Tejon Mill (approx 15 mi N)	---	---	---	---	VII, VIII
Fort Yuma	IX	IX	--	--	
German Station (below Gorman)	--	--	Identify	--	
Iowa Hill	---	---	---	---	
Kern Lake	---	---	---	---	X
Kern River Valley	Intensity unassigned	Intensity unassigned	Identify	VII-VIII	VII, X, XII
Los Angeles	--	--	Identify	VI	III, V, VI, X
Los Angeles River	IX	IX	Identify	--	
Mariposa	--	--	--	Not felt	
Marysville	--	--	--	Felt	Felt
Mill Potrero-Lake Hughes (SAF)	--	--	--	IX+	IX+
Millerton	---	---	---	---	II
Michigan Bluffs	---	---	---	---	
Mojave River (upper)	--	--	--	VII	III, VII
Mojave Valley	Intensity unassigned	Intensity unassigned	Identify	--	III+
Mokelumne Hill	--	--	--	Not felt	IV, V
Mokelumne River	Intensity unassigned	Intensity unassigned	Identify	--	
Monte					VII, VIII
Monterey	--	--	Identify	IV?	III+
Mouth of Colorado River	--	--	Identify	V?	V?
Muscapiabe In Res (N of Asylum)	--	--	Identify	--	
Nevada	---	---	---	---	
Oakland	---	---	---	---	
Paredes	--	--	Identify	--	
Petaluma	---	---	---	---	
Point Argnello	--	--	--	Felt	Felt
Point Conception	--	--	--	Felt	Felt
Rancho San Benito	--	II or Felt	--	VI-VII?	
Reed's Rancho	---	---	---	---	X-XI
Sacramento	VI	VI	Identify	V	II, V, VI
Salinas River	--	--	--	VI	VI
San Benito Ranch	---	---	---	---	VI-VII?
San Benito & River	VIII or IX?, II	Unassigned, II	--	VI-VII	VI-VII
San Bernardino	IX	IX	Identify	VI	II, III, V, VI, VII, X
San Buenaventura (Ventura)	IX	IX	Identify	VII	VII+
30 miles SE (Canyon area)	---	---	---	---	IV-V
San Diego	IX	IX	Identify	V	III, VI, VIII
San Fernando Valley	IX	Intensity unassigned	Identify	VII	VII
San Francisco	--	--	Identify	II-V	IV-VIII
San Gabriel Valley/River	Intensity unassigned	Intensity unassigned	Identify	VII	VII
San Joaquin Valley	--	--	Identify	--	
San Jose	--	--	--	IV-V	IV-V
San Juan	---	---	---	---	
San Pedro	---	---	---	---	VIII
Santa Amelia Area	---	---	---	---	
Santa Barbara	Intensity unassigned	Intensity unassigned	Identify	VI	VI
Santa Catalina Island	--	--	--	Felt	Felt
Santa Clara Valley/River	Intensity unassigned	Intensity unassigned	Identify	--	
Santa Cruz	--	--	--	V	V
Santa Cruz Island	--	--	--	Felt	Felt
Santa Rosa Island	--	--	--	Felt	Felt
Sebastian Indian Reservation (Tejon)	--	--	--	VII-VIII	VII-VIII
Sierra County	---	---	---	---	
Simi	---	---	---	---	
Stockton	--	--	--	IV	IV
Sycamore Canyon	--	--	Identify	VII	VII
Temblor Range/Carrizo Plain	--	--	Identify	--	
Temple's Ranch (20mi S of LA)	--	--	Identify	--	
Tulare Lake	IX	IX	Identify	VI-VII	X
Tulare River					
Visalia	IX	IX	Identify	(V-VI)	V-VI
White River	--	--	?	V-VI	V-VI

KEY

*Intensities based on Rossi-Forel Scale

**Intensities based on Modified Mercalli Index

Appendix 4. Example of a complete transcription of a letter from Ft. Tejon Surgeon Peter TenBroeck reporting on the main shock and aftershocks of 9 January 1857 earthquake.

Fort Tejon, Cala.
July 3rd 1857.

Colonel,

Wherewith enclosed I have the honor to forward
You a Table of the different Shocks of Earthquaques,
Which have been experienced at this Port from 9th of Jan.
1857, up to the present time. I enclose you a Copy of
my Report on the Shocks of the 9th of Jan. to the Surgeon
Genl, also.

I would remark, that these (recorded on the Table)
are only the Shocks, that have come under the personal ob,,
servation of the Hospital Steward, or myself. But that at
least as many more, as are recorded, have passed unnoticed.

Latterly, the majority of the Shocks have occurred du,,
Ring the night, and we have become so accustomed to them,
That they do not wake us, as formerly, so that unless
We chance to be awake at the time, they are not noticed.

Also in case of slight Shocks occurring, they are not
perceptible to a person, who is walking (on the ground),
or riding at the time.

The Shocks are generally oscillatory, but we have now
And then a vertical one.

The first Shock of the Earthquaque and those which
Succeeded is during the month of January, were felt over
A large extent of country, but since then the circle has
Been constantly diminished, and for the last three months
the Shocks have been confined almost exclusively to the
[pg 2] Post, and its immediate vicinity.

Severe Shocks felt here, are not perceptible at the destan.
ce of a few miles, and I have even noticed, that they vary
in intensity at the distance of only a few hundred yards;
thus a Shock which is quite severe at the Sutlers Store
will appear very slight in the garrison.

It would certainly seem, that we are in the very
centre of the disturbance, and that the „Head Quarters" of
the Earthquaue are at no great distance from us.

Along the line, or rifs of the Earth, which was made
by the first great Shock, and where its effects as that time
were so terrible, the Shocks have ceased to be felt for some
Months.

Although the Shocks have continued now nearly six
Months, we can hear nothing of the opening of any Crater
In our vicinity, though we had reports to that effect
in the early part of January.

For the last t[h]ree months the Shocks have been gene,,
rally very slight, with now and then a severe one, but
no perceptible dimination in either frequency or intensity.
The only difference is, that we have become accustomed
to them, and they do not affect us as at first. Accasio,,

nally the though will strike us, that perhaps another
will come equal in severity to the first, which would
undoubtedly destroy nearly all the buildings at the Post,
strained & shattered as they are from the previous
Shocks.

[pg 3] Judging from the experience of the last few months,
there seems as little probability as ever of the entire ces,,
sation of the Shocks.

The topography of the Post, is another Point; to
Which I would beg leave to call your attention, in con,,
nection with the subject of Earthquaque.

Situated in a Cañada [Canyon] or Valley of only a few hun,,
dred yards in width, and surrounded on all sides by very
high mountains, should there at any time occur a ,,land
slide" as sometimes happens in Mountanous Countries,
in connection with severe convulsions of the Earth, the
whole valley would be inevitably filled up.

I have been stationed nearly three [scribbled over "four"?] years here,
And the last winter and present summer have been
the coldest, we have experienced.

I am fin[?]

very respectfully
your obt.[obedient] servt [servant]
P.G.S. To[e]n Br[o]eck
Asst Surg
U. S. A

Col. Thos. T. Fountberoy
1st u st. Dragoons, lmdg Ft [raised t] Tejon.

[Outside of letter on envelope]

Fort Tejon Cal.
July 3. 1857

1
F. g. ,Dept Pac, July 6. 1857.

PGS. Ten Broeck
Asst Srg. – U.S.A.

In relation to earthquaks
at Fort Tejon Cal.

N° 1-